Evaluation and Modification of Open-Web Steel Joists and Joist Girders

Perry S. Green, Ph.D., Technical Director

Steel Joist Institute

Myrtle Beach, SC

Introduction

- **Commercial manufacture of open web steel joists began in 1923**
- **The Steel Joist Institute was formed in 1928**
  - Steel joist use has continued to grow
  - There are millions of joists in service

Introduction (cont'd)

Evaluation and Modification of joists are required for many reasons:

- **Building renovations**
- **Addition of roof top units**
- **Conveyor loads**
- **Field deviations**
- **Other changes not contemplated in the original design**

New Resource Available

SJI Technical Digest No. 12

Evaluation and Modification of Open-Web Steel Joists and Joist Girders

- **Present procedures**
- **Suggest details for modification or strengthening**

SJI Technical Digest No. 12

- *BACKGROUND*
- *GLOSSARY*
- *Chapter 1* EVALUATIONS OF EXISTING JOIST STRENGTH
- *Chapter 2* METHODS OF SUPPORTING ADDITIONAL LOAD
- *Chapter 3* DESIGN APPROACHES FOR STRENGTHENING JOISTS
- *Chapter 4* DESIGN APPROACHES FOR MODIFYING JOISTS- SHORTENING AND LENGTHENING
- *Chapter 5* OTHER CONSIDERATIONS
- *Chapter 6* SUMMARY
- *REFERENCES*
- *APPENDIX A* JOIST INVESTIGATION FORM
- *APPENDIX B* COMMON PROPERTIES OF EQUAL LEG ANGLES WITH LEG SIZES 2 IN. OR LESS

Glossary of Terms

- Allowable Strength Design (ASD)
- Allowable Strength
- Available Strength
- Bearing
- Bridging
- Buckling
- Buckling Strength
- Camber
- Chords
- Cold-Formed Steel Structural Member
- Composite Section
- Connection
- Deck
- Design Load
- Design Strength
- End Diagonal or Web
- End Welds
- Existing Member
- Filler
- Joint
- Joist
- Joist Girder

Glossary of Terms

- Load
- LRFD (Load and Resistance Factor Design)
- Material
- Nominal Strength
- Preload Force
- Reinforcing Member
- Required Strength
- Resistance Factor, Φ
- Safety Factor, Ω
- Slenderness Ratio
- Span
- Specified Minimum Yield Stress
- Specifying Professional
- Splice
- Stability
- Standard Specifications
- Structural Analysis
- Tagged End
- Webs
- Yield Point
- Yield Strength
- Yield Stress

Chapter 1 Evaluation of Existing Joist Strength

Determine Capacity of Existing Joist System

- As-built design of joists
- Existing joists possibly over specified
- Building usage may have changed
- Have joists been damaged

As - Built Design of Joists

How to Determine

- **Original contract structural documents**
- **Final joist erection drawings**
- **Year job was constructed**
- **Joist manufacturers identification tag**
- **Field investigation and measurements**

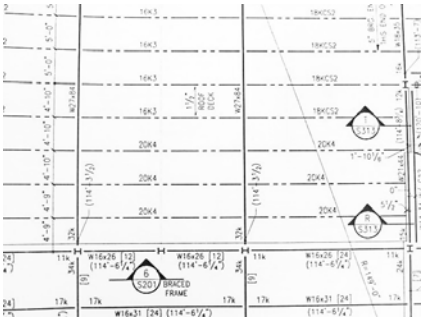
Joist Drawings

Structural Drawing

- Designation
- Joist Spacing

Erection Drawing

- Designation
- Joist Spacing
- Mark Number



2005 SJI Catalog

- **K-Series Standard Specifications**
  - K-Series Load Tables
  - KCS Joists
- **LH- and DLH-Series Standard Specifications**
  - LH- and DLH-Series Load Tables
- **Joist Girders Standard Specifications**
  - Joist Girder Weight Tables

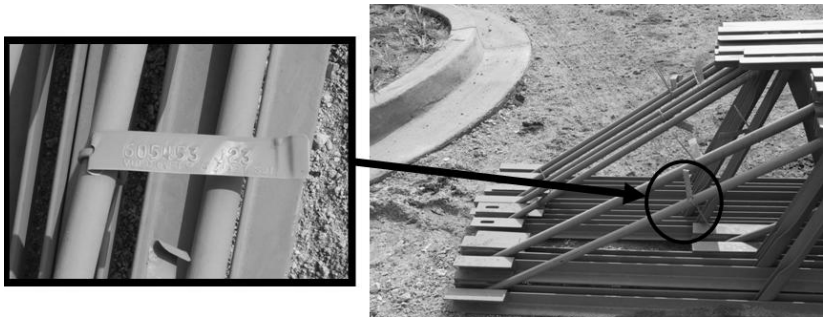
ORDER FROM:

- www.steeljoist.org

Joist Identification Tag

Joist tag information

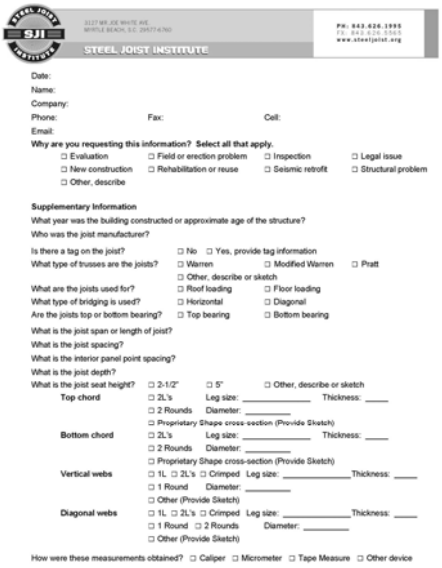
- **Joist manufacturer's name**
- **Joist manufacturer's job number**
- **Erection mark number, e.g. J1 or T3**



Joist Investigation Form

Steel Joist Institute Assistance

- Fill out the Form On-line
- Download from SJI website
  - **www.steeljoist.org**
  - **Return to SJI office for assistance**



STEEL JOIST INSTITUTE

Date:
Name:
Company:
Phone: Fax: Cell:
Email:

Why are you requesting this information? Select all that apply.

☐ Evaluation ☐ Field or erection problem ☐ Inspection ☐ Legal issue
☐ New construction ☐ Rehabilitation or reuse ☐ Seismic retrofit ☐ Structural problem
☐ Other, describe

Supplementary Information

What year was the building constructed or approximate age of the structure?
Who was the joist manufacturer?

Is there a tag on the joist? ☐ No ☐ Yes, provide tag information
What type of trusses are the joists? ☐ Warren ☐ Modified Warren ☐ Pratt
☐ Other, describe or sketch
What are the joists used for? ☐ Roof loading ☐ Floor loading
What type of bridging is used? ☐ Horizontal ☐ Diagonal
Are the joists top or bottom bearing? ☐ Top bearing ☐ Bottom bearing
What is the joist span or length of joist?
What is the joist spacing?
What is the interior panel point spacing?
What is the joist depth?
What is the joist seat height? ☐ 2-1/2" ☐ 5" ☐ Other, describe or sketch

Top chord ☐ 2Ls Leg size: _____ Thickness: ____
☐ 2 Rounds Diameter: _____
☐ Proprietary Shape cross-section (Provide Sketch)

Bottom chord ☐ 2Ls Leg size: _____ Thickness: ____
☐ 2 Rounds Diameter: _____
☐ Proprietary Shape cross-section (Provide Sketch)

Vertical webs ☐ 1L ☐ 2Ls ☐ Crimped Leg size: _____ Thickness: ____
☐ 1 Round Diameter: _____
☐ Other (Provide Sketch)

Diagonal webs ☐ 1L ☐ 2Ls ☐ Crimped Leg size: _____ Thickness: ____
☐ 1 Round ☐ 2 Rounds Diameter: _____
☐ Other (Provide Sketch)

How were these measurements obtained? ☐ Caliper ☐ Micrometer ☐ Tape Measure ☐ Other device

Field Investigation

Helpful and Required Information

- **Loading on the joists**
- **Information from the joist tags**
- **Joist configuration**
- **Joist span**
- **Joist spacing**
- **Joist depth or height**
- **Bearing condition**
  - Underslung or Bottom Bearing

Field Investigation

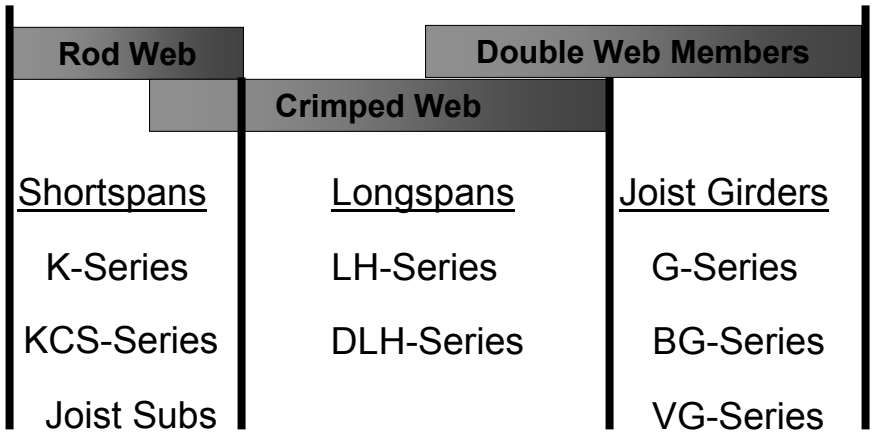
Type of Web Members

- Rod webs
- Crimped Angle webs
- Angles welded to the outside of chords
- Cold-formed sections

Also Take Note of

- End Diagonal type
- Eccentricities
- Weld Sizes and lengths
- Panel Point spacing

Comparison of SJI Specification Types



Field Investigation

Type of Chord Members

- **Double Angles**
  - Separation distance
  - Fillers or ties
- **Cold-formed sections**
- **Rods**
- **Splices**

Field Investigation

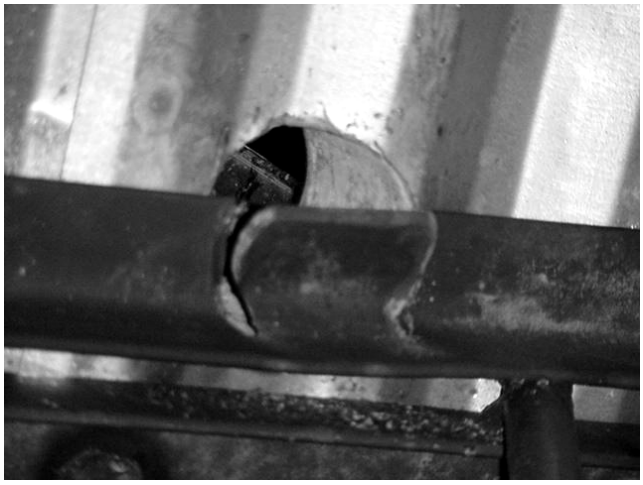
Other Items to Note

- **Type of Bridging and Locations**
- **Quality of bridging connections**
- **Anchorage of bridging**
- **Interferences**
- **Coupon samples to determine yield strength**
- **Condition of joists and existing deck**

Joist Chord Damage During Handling

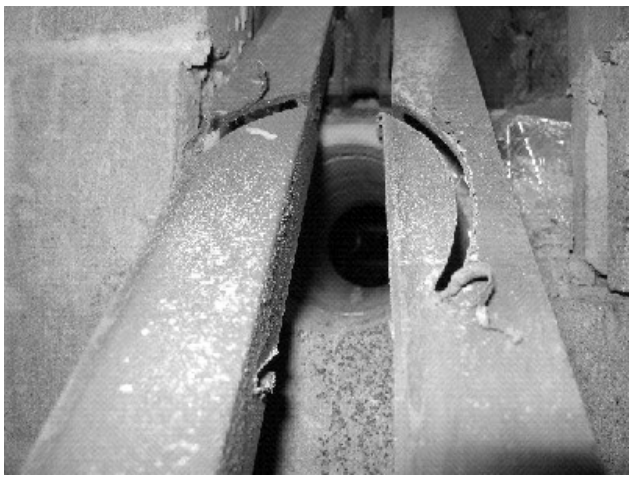
Joist BC Damage During Handling

Joist TC Damage During Construction



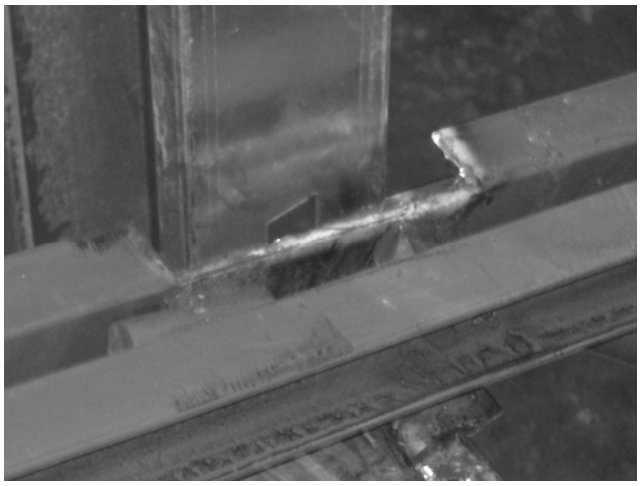
Joist End Web Damage During Construction

Joist End Web Damage During Construction



Joist BC Damage During Construction

Joist TC Damaged During Construction



OSHA Federal Regulation 29 CFR 1926.757(a)(7)

No modification that affects the strength of a steel joist or steel joist girder shall be made without the approval of the project structural engineer of record.

Analysis Considerations

To Analyze Joist Capacity

- **Pinned connections are assumed for web members**
- **Specifications for K-Series joists permit bending to be neglected when**
  - Panel point spacing does not exceed 24 inches
  - The applied loads are uniform
- **A first-order analysis is used**
- **The SJI permits eccentricities to be neglected when**
  - For K-Series, the “3/4 Rule” is followed
  - For all other joist series, when the eccentricity “… does not exceed the distance between the centroid and back of the chord”

Example 1.1 Determine if a Joist Requires Reinforcement

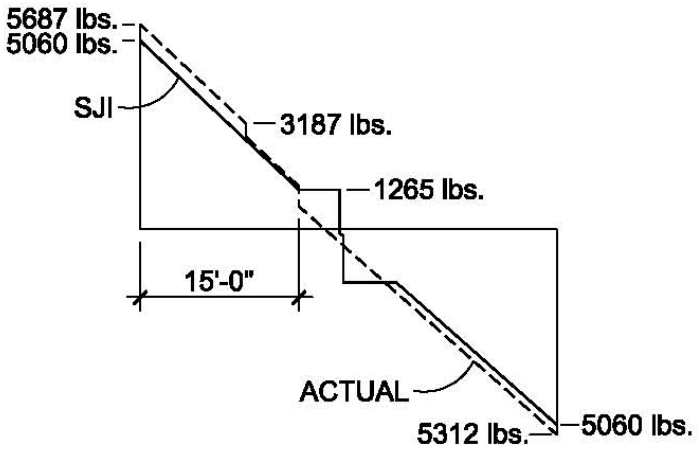
Scenario

- **A roof top unit is to be added to two 24K7 joists spanning 40 feet**
- **Unit adds two, 500 lb. point loads to each joist**
  - Located 10 ft. and 15 ft. from one end
- **It has been determined that the uniform load on the joist is 250 PLF**

Determine if the joist must be reinforced

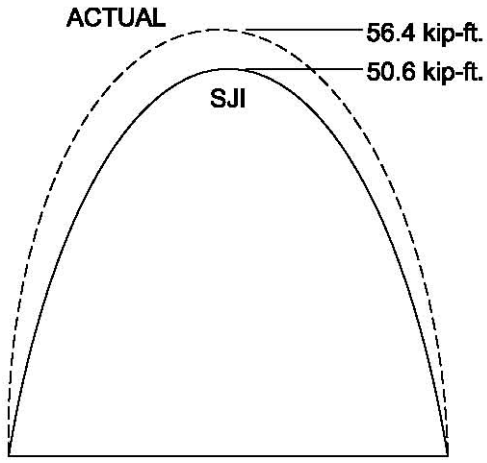
Example 1.1

Shear Envelope for 24K7 Joist



Example 1.1

Moment Diagram for 24K7 Joist



Chapter 2 Methods of Supporting Additional Load

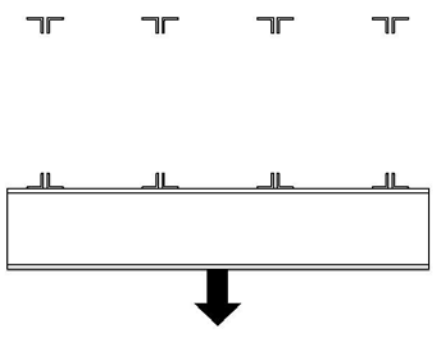
Options Before Strengthening

- Capacity of joist needs to be determined
  - Can joist safely support new loads?
- Extensive reinforcement may not be practical
  - Option #1- Load distribution
  - Option #2- Add new joists or beams
  - Reinforce existing joists

Load Distribution

Member with Suitable Stiffness Required

- Place member under or through the joists
- Concentrated load distributed to several joists



Load Distribution

Relative Stiffness is Defined by Beta

$$\beta = \sqrt[4]{\frac{(K/S)}{(4EI)}} \qquad \textbf{Eq. 2-1}$$

Where,

K = stiffness of the joist, kips/in.
S = spacing of the joists, in.
E = modulus of elasticity for the beam, ksi
I = moment of inertia of the beam, in.^{4}
β = characteristic parameter, 1/in.

Load Distribution

$$\beta = \sqrt[4]{\frac{(K/S)}{(4EI)}}$$

If S is less than π/4β

- The spacing limit is not exceeded
- S = spacing of the joists, in.

If the length of the beam is less than 1/β

- The beam may be considered rigid
- Joist reactions may be determined by static equilibrium.

Example 2.1 Underhung Monorail Beam using Load Distribution

This example will illustrate:

- **How load distribution can eliminate the need for strengthening**
- **How to minimize the amount of strengthening by reducing the load to each joist**
- **How to design the distribution beam placed beneath the joist bottom chord**

Example 2.1 Underhung Monorail Beam using Load Distribution

Given Conditions:

- **Hang new underhung monorail beam from the bottom chord of several joists**
- **Joists are 30K12 spanning 36'-0"**
- **Joists are spaced 2'-6" o.c.**
- **Monorail adds a 1200 lb. concentrated load**
  - Concentrated load located 10'-0" from joist end

Example 2.1 Underhung Monorail Beam using Load Distribution

Determine the stiffness of the joists:

Determine approx. moment of inertia from

$$I_j = 26.767\left(W_{LL}\right)\left(L^3\right)\left(10^{-6}\right) \qquad \textbf{Eq. 2-2}$$

where,

W_{LL} = nominal live load that will produce an approximate deflection of Span/360 (RED figure in the Load Table)

L = (Span – 0.33), ft.

Example 2.1 Underhung Monorail Beam using Load Distribution

Determine the stiffness of the joists:

Determine approx. moment of inertia from

$$I_j = 26.767\left(W_{LL}\right)\left(L^3\right)\left(10^{-6}\right) \qquad \textbf{Eq. 2-2}$$

From the Load Table, the live load deflection for a 30K12 joist with a 36'-0" span is:

W_{LL} = 392 plf

$$I_j = 26.767\left(392\right)\left(35.67^3\right)\left(10^{-6}\right) = 476 \text{ in.}^4$$

Example 2.1 Underhung Monorail Beam using Load Distribution

Divide I_j by 1.15 to account for shear deflection:

$$I_{j,eff} = \frac{476}{1.15} = 414 \ in.^4 \qquad K = \frac{P}{\Delta}$$

From AISC Manual of Steel Construction, Table 3-23 for a simple beam- concentrated load at any point:

$$\Delta = \frac{Pa^2b^2}{3EIL} \quad \textbf{Thus,} \quad K = \frac{P}{\Delta} = \frac{P}{\frac{Pa^2b^2}{3EI_{j,eff}L}} = \frac{3EI_{j,eff}L}{a^2b^2}$$

$$K = \frac{3(29000)(414)(35.67)(12)}{[(26)(12)]^2[(10)(12)]^2} = 11.0 \ k/in.$$

Example 2.1 Underhung Monorail Beam using Load Distribution

Determine the beam size necessary to distribute the load to three (3) joists:

Try W16 x 26 I_x = 301 in.^{4}

$$\beta = \sqrt[4]{\frac{(K/S)}{(4EI)}} = \sqrt[4]{\frac{11.0/30}{(4)(29000)(301)}} = 0.0101 \ in.^{-1}$$

Check if spacing, $S < \frac{\pi}{4\beta} = 77.6$ in.

S = 30 in. < 77.6 in. **Therefore, OK**

Example 2.1 Underhung Monorail Beam using Load Distribution

Determine the beam size necessary to distribute the load to three joists:

For W16 x 26 **$\beta = 0.0101$ in.$^{-1}$**

Check the length of monorail support beam $< \frac{1}{\beta}$ *in.*

Beam Length L= 5.0 ft. = 60 in.

1/β = 1/0.0101 = 98.8 in.

60 in. < 98.8 in. **Therefore, OK**

Example 2.1 Underhung Monorail Beam using Load Distribution

Solve for the reaction at each joist:

Since the beam can be considered rigid, 1200 lbs. can be uniformly distributed to each joist support

1200 lbs. / 4 = 300 lbs. additional load

Note: Don't forget to include the beam self-weight. It might not be insignificant.

Adding New Joists or Beams

Considerations:

- **Existing interferences**
  - Piping, electrical conduits, other interferences
  - Removing or relocating could be at a greater expense than reinforcement
- **Camber**
  - May need to reduce camber in new joists
  - Joists can be ordered with shallower seat depths and then shimmed in the field
  - The joist can be supplied with a splice so two individual pieces can be installed and bolted at the center
- **Lateral Stability of the joist top chord**
  - Shoot pins through the chord, decking, and slab
  - Rely on bridging to provide lateral support

Reinforcing Existing Joists

The following has a major impact on reinforcement of both chord and web members:

- **Rod web members**
- **Crimped angle web members**
  - Many crimped web joists have rod end webs
- **Web angles welded to the sides of the chords**
- **Geometry of the chords**
- **Chord and web yield strength**

Reinforcing Existing Joists

Other considerations:

- **Additional weld may be required even though web member size is sufficient for new loads**
- **Accessibility to reinforce either chord or webs**
  - May only be able to reach one side of the joist
- **Eccentricities**

Chapter 3 Design Approaches for Strengthening Joists

Two Design Approaches to Reinforce Individual Joist Members

- **Approach I**
  - Ignore the existing member strength
  - Simply design the reinforcing members to carry the total load
- **Approach II**
  - Make use of the strength of the existing member

Design Approaches for Strengthening Individual Joist Members

Considerations for Either Approach

- **Cost of materials for reinforcement is insignificant to the cost of labor**
- **Safest to reinforce the joist in the shored position**
  - Welding can generate enough heat to cause temporary loss of steel strength
  - Transverse field welds should be avoided
- **Best to reinforce the members with dead and live loads removed**
  - Jack the joist up to a calculated deflection
- **Pay close attention to eccentricities caused by the reinforcing**

Design Approaches for Strengthening Individual Joist Members

For Approach II

- **It is assumed that applied forces are distributed between the existing member and the reinforcing member**
  - Direct proportion to their areas
- **If joists are shored to remove existing load**
  - The preload is then zero
- **If joists are not shored**
  - Preload can be calculated based on load present at the time of reinforcing
- **Shoring and jack placement is the responsibility of the Specifying Professional**

Design of Reinforcing for Tension Members (Approach II)

1. **Determine the total area required, A_{tr}**

$$A_{tr} = \frac{(P_t - P_p)}{(P_o - P_p)} A_e$$

Where,

A_{tr} = Total area required (existing member and required reinforcing), in.^{2}

A_e = Area of existing member, in.^{2}

P_0 = Original force for the existing member (original design force), kips.

P_p = Preload in the existing member at the time of reinforcing, kips.

P_t = Required strength, kips.

Assumes existing steel and reinforcing steel both have equal yield strength

Design of Reinforcing for Tension Members (Approach II)

Design procedures when the yield strengths of the two materials are not equal:

- **Assume both materials have the same yield strength as that of the lowest material used**
  - Most conservative method
- **Use the actual yield strength of each material in the design**
  - Allow each material to achieve the full allowed stress level

Design of Reinforcing for Tension Members (Approach II)

2. **Determine required area of reinforcing, A_r**

$$A_r = A_{tr} - A_e$$

3. **The force in the reinforcing member equals**

$$P_r = \left(\frac{A_{fr}}{A_t}\right)\left(P_t - P_p\right)$$

Where,

A_{fr} = Area of the furnished reinforcing, in.^{2}

A_t = Area of existing member plus the area of the furnished reinforcing, in.^{2}

Design of Reinforcing for Compression Members (Approach II)

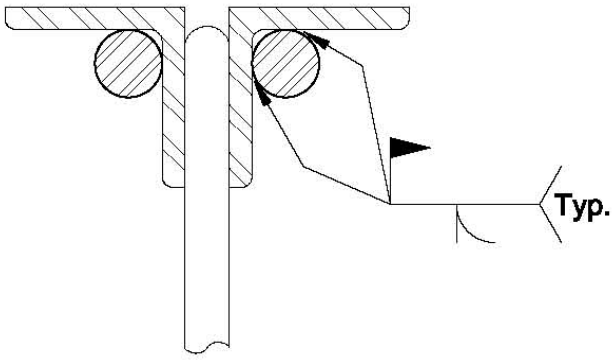
1. **Select a trial reinforcing member.**
2. **Check the buckling strength of the composite member.**
   - If a preload force exists, determine the magnitude of the compressive stress in the existing member due to the preload, f_p
   - F_{ye} = minimum yield stress of existing member, ksi
   - For the buckling check, use F_y as the minimum of **$(F_{ye} - f_p)$ or F_y**
3. **Design the weld for the reinforcing member. The force in the weld is** $P_{rw} = \left(\frac{A_{fr}}{A_t}\right)\left(P_t - P_p\right)$

Chord Reinforcement

Typical reinforcement details

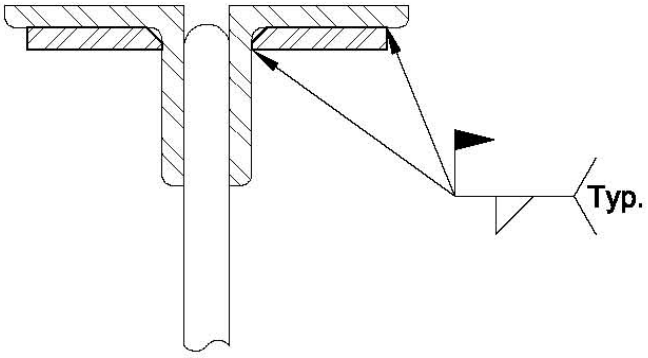
- **Top chord**
  - More difficult to reinforce since the floor or roof deck is usually in place
  - Overhead welds may be required
- **Bottom chord**
  - Easier to access
  - No overhead welds required

Chord Reinforcement



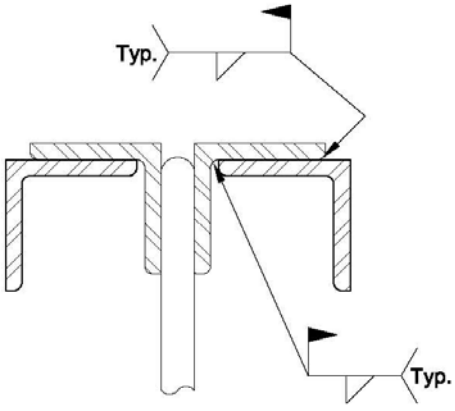
Top Chord Reinforcement - Rods

Chord Reinforcement



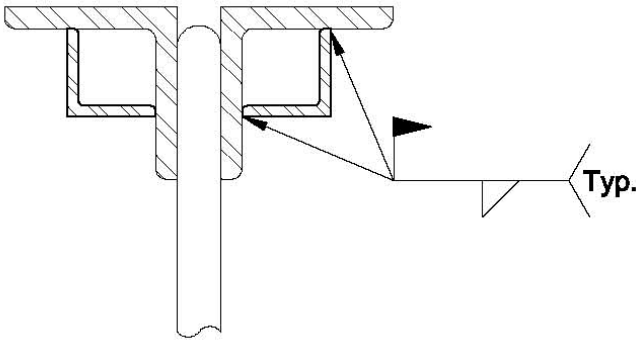
Top Chord Reinforcement - Plates

Chord Reinforcement



Top Chord Reinforcement - Angles

Chord Reinforcement

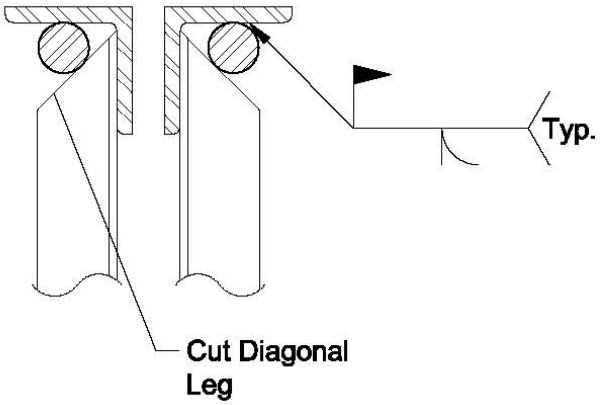


Top Chord Reinforcement - Angles

Chord Reinforcement

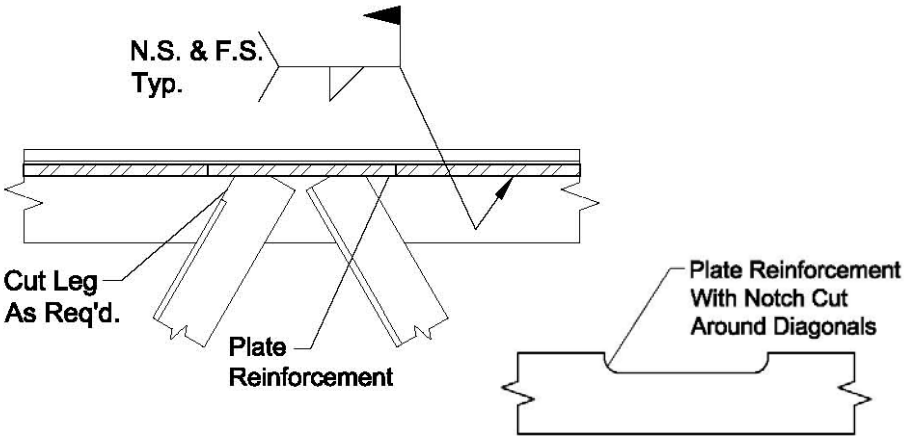
Angle Interference with Top Chord Reinforcement

Chord Reinforcement



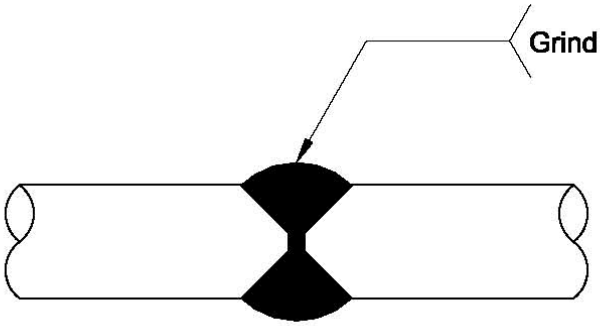
Top Chord Reinforcement - Rods

Chord Reinforcement



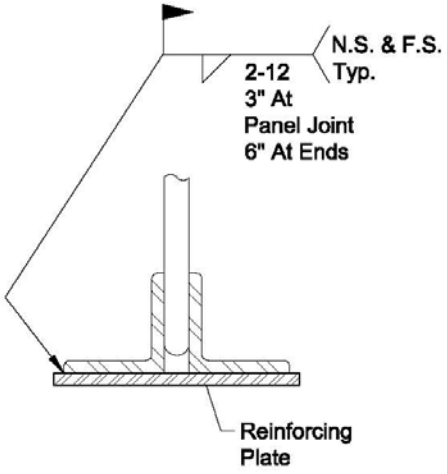
Top Chord Reinforcement Requiring Notch

Chord Reinforcement



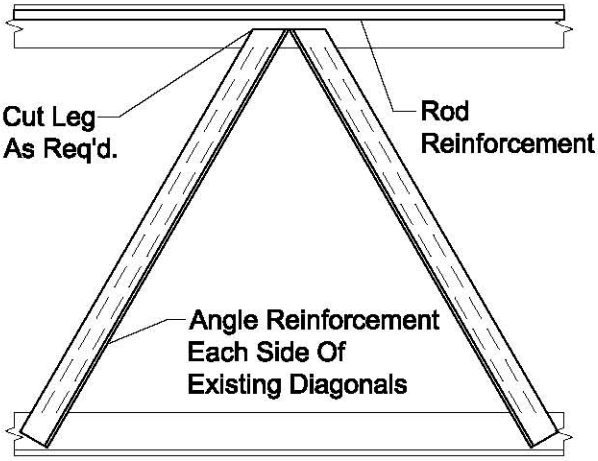
Rod Splice

Chord Reinforcement



Bottom Chord Reinforcement

Rod Web Reinforcement



Angle Reinforcement on Rod Web Joist

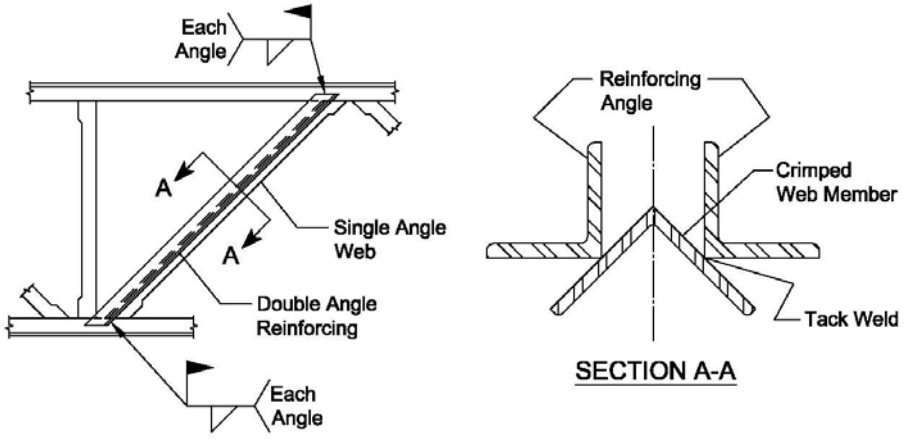
Rod Web Reinforcement

Angle Reinforcement on Rod Web Joist

Crimped Web Reinforcement

Joist with Crimped Web Members

Crimped Web Reinforcement

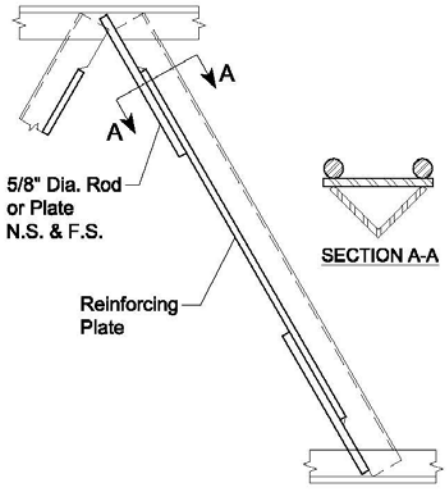


Angle Reinforcement on Crimped Web Joist

Crimped Web Reinforcement

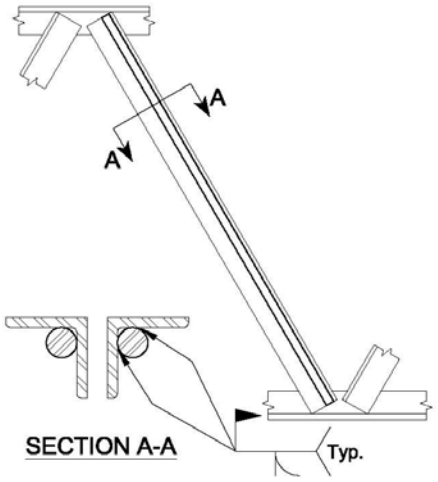
Angle Reinforcement on Crimped Web Joist

Crimped Web Reinforcement



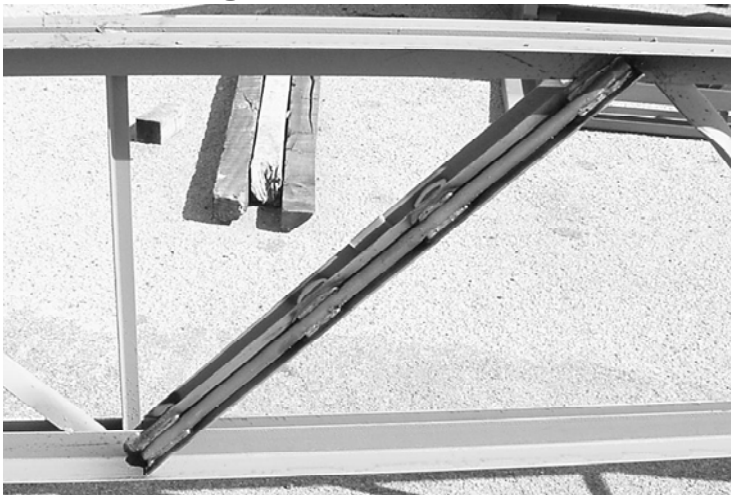
Crimped Web Reinforcement

Double Angle Web Reinforcement



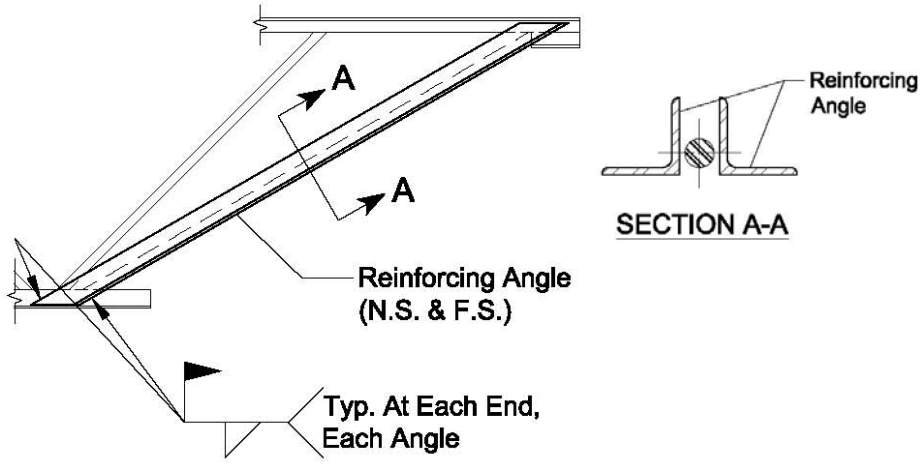
Angle Web Reinforcement with Rod

Double Angle Web Reinforcement



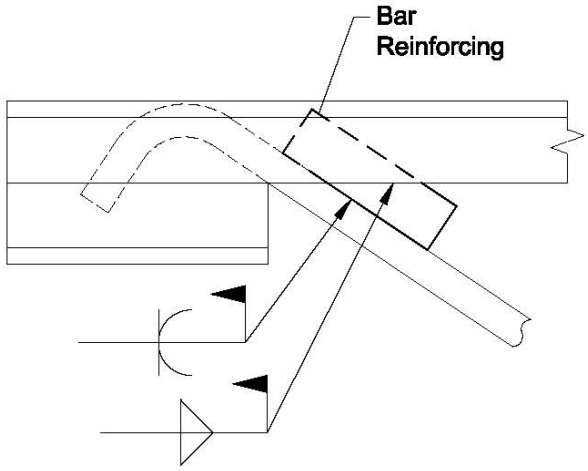
Angle Web Reinforcement with Rod

End Diagonal Web Reinforcement



End Diagonal Reinforcement with Angle

End Diagonal Web Reinforcement



Bar Added for Additional Weld on End Diagonal

Design Examples for Strengthening Joists

Example 3.1 Strengthening a K-Series Joist with Crimped Angle Webs

Example 3.2 Strengthening a K-Series Joist with Rod Webs

Example 3.3 Strengthening an End Diagonal (W2) using Double Angles

Example 3.4 Strengthening of Joist Girder Chords

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

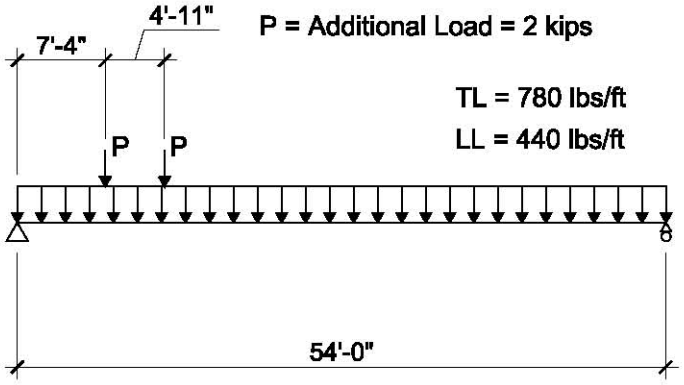
Example 3.6 Design of a Strut to Prevent Top Chord Bending between Panel Points

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

Given Conditions:

- **A remodel requires that additional equipment be installed and supported by the joists**
- **Original joists were designated as 32LH780/440**
- **Added equipment will be centered over two joists**
  - Resulting load is 2000 lbs located at 7'-4" and 12'-3" from the tag end of the joist
- **Uniform loads in the designation are the uniform design loads required**
  - Load redistribution method not a feasible solution

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs



32LH780/440 with Additional Concentrated Loads

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

Analysis:

- **Overstressed webs are double angles**
- **Axial force in the end web member (W2)**
  - Required force = 60.5 kips
  - Allowable force (from manufacturer) = 56.3 kips
- **First compression web member (W3)**
  - Required force = 18.1 kips
  - Allowable force (from manufacturer) = 17.2 kips
- **Originally designed using Allowable Stress Design**
  - Use (ASD) for reinforcement also

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

End Web Reinforcing:

Load in end tension web (W2) at time of reinforcing is 23.0 kips

Total area required = $A_{tr} = \frac{(P_t - P_p)}{(P_o - P_p)} A_e$

Where:

P_t = 60.5 kips (required force)

P_p = 23.0 kips (preload force)

P_o = 56.3 kips (original allowable design force)

A_e = 1.1876 in.^{2} (area of two 2 x 2 x 0.250 angles)

Thus, $A_{tr} = \frac{(60.5 - 23.0)}{(56.3 - 23.0)} (1.876) = 2.113 \text{ in.}^2$

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

The required area of reinforcing =

$$A_r = A_{tr} - A_e = 2.113 - 1.876 = 0.237 \text{ in.}^2$$

Add round rods for reinforcement

Two ¾" diameter rods placed in heel of angles

Area of furnished reinforcing,

$A_{fr} = \frac{2\pi d^2}{4} = \frac{2\pi (0.75)^2}{4} = 0.884 \text{ in.}^2$ > 0.237 in.^{2}

Therefore, OK

The total area, A_t, is the sum of the areas of the existing web angles plus the areas of the reinforcing rods,

$$A_t = A_e + A_{fr} = 1.876 + 0.884 = 2.760 \text{ in.}^2$$

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

The force in the reinforcing members equals

$$P_r = \left(\frac{A_{fr}}{A_t}\right)(P_t - P_p) = \left(\frac{0.884}{2.760}\right)(60.5 - 23.0) = 12.01 \text{ kips}$$

Check the stress in the round rod reinforcing member:

F = P/A =12.01/0.884 = 13.59 ksi < 21.6 ksi

Therefore, the use of A36 material is OK

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

End Web Reinforcing Weld Design:

Joint between Rod and Angle will be a partial-joint-penetration groove weld.

Effective throat thickness of 5/16 times the rod radius. (AISC Specification Table J2.2 for Flare Bevel Groove weld)

Effective throat = 5/16 x $\frac{3/4"}{2}$ = 0.117 in.

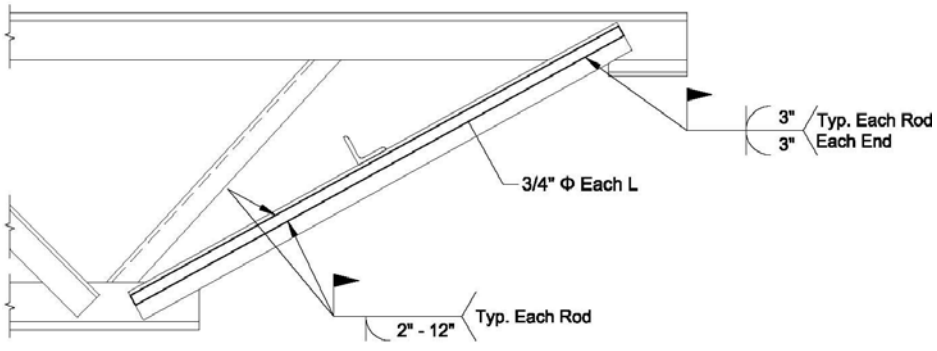
Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

Allowable shear per weld using E70 electrodes from AISC Table J2.5, Available Strength of Welded Joints is 2.46 kips/in.

The total length of weld required to develop the force in each rod **=12.01 / 2.46 = 4.88 in.**

The 6 in. of weld shown in the following figure, at the ends of each reinforcing rod, is more than adequate.

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs



Reinforcing End Diagonals

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

End Web Weld Design for Total Required Force:

P_t = 60.5 kips

Based on 3/16" fillet weld and using E70 electrodes, the allowable shear per inch of weld equals:

(0.707)(0.188 in.)(21 ksi) = 2.79 kips/in.

Thus, 60.5/2.79 = 21.7 in.

(use 11 in. at each end of each web angle)

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

Check for Tensile Rupture

Conservatively, U can be taken as 0.6 or can be determined from AISC Specification Table D3.1, **Shear Lag Factors for Connections to Tension Members**.

When Case 2 is selected, $U = 1 - \frac{\bar{x}}{\ell}$ Case 2

U depends on the weld arrangement. AISC does not address the condition of unequal weld lengths on the heel and toe of the angle so use the length along the heel.

Assume that 4 in. of weld is placed on the heel, 7 in. along the toe.

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

Check for Tensile Rupture

Where:

$\overline{X}$ is the centroid location for the composite section comprised of web angle plus the round rod

ℓ is the length of the connection

$\overline{X}$ = (0.25 + 0.375) = 0.625 in. **ℓ = 4 in.**

$$U = 1 - \frac{0.625}{4} = 0.844$$

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

The nominal strength P_n based on tensile rupture equals

F_uA_e or UF_uA_t

F_u = 65 ksi since the weld is placed on the angle

$$P_n = UF_uA_t = (0.844)(65)(2.760) = 151.4 \text{ kips}$$

$$P_{available} = \frac{P_n}{\Omega_t} = \frac{151.4}{2.00} = 75.71 \text{ kips}$$ **> 60.5 kips Therefore, OK**

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

First Compression Web Reinforcing

Design Approach II:

1. **Select a trial reinforcing member.**
2. **Check the buckling strength of the composite member.**
   a. Determine the magnitude of the compressive stress in the existing member due to the preload, f_p
   b. F_{ye} = minimum yield stress of existing member, ksi
   c. For the buckling check, use F_y as the minimum of **$(F_{ye} - f_p)$ or F_y**
3. **Design the weld for the reinforcing member. The force in the weld is** $P_{rw} = \left(\frac{A_{fr}}{A_t}\right)\left(P_t - P_p\right)$

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

First Compression Web Reinforcing (cont'd)

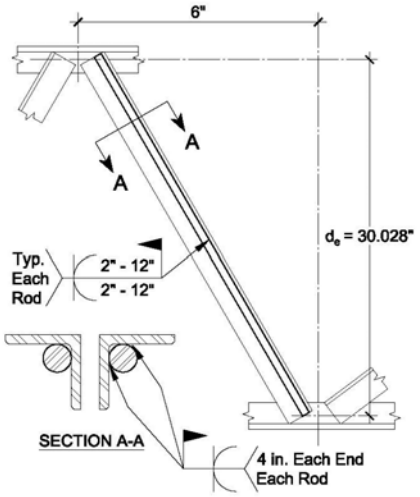
The req'd load in the first compression web (W3) is 18.1 kips

Solution:

1. **Trial reinforcing member.**
   - Try 2- ¾" diameter rods, F_y = 36 ksi
2. **Determine composite properties of combined section shown in Section A-A of the Figure on the next slide.**
   - The total area, A, is the sum of the existing web angles plus the areas of the reinforcing rods, $A_t = A_e + A_{fr}$
   - Area of existing 1.5x1.5x0.138 web angles,
     $A_e = 2(0.395) = 0.790$ in.^{2}
   - Area of the furnished reinforcing,

$A_{fr} = 2\pi d^2/4 = 2(0.442) = 0.884$ in.^{2} $\quad A_t = 0.790 + 0.884 = 1.674$ in.^{2}

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs



Double Angle Reinforcing with Rod

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

Determine composite properties

The location of the centroid of the composite section with respect to the x-axis is:

$$\bar{y} = \frac{1}{A_t}\sum A_i \bar{y}_i$$

$$\bar{y} = \frac{1}{1.674}\left[(0.884)(0.138 + 0.375) + (0.790)(0.426)\right] = 0.472 \text{ in.}$$

The moment of inertia of the composite section with respect to the x-axis is:

$$I_x = \sum \left(I_i + A_i d_i^2\right)$$

$$I_x = 2\left[0.085 + 0.395(0.426 - 0.472)^2 + 0.016 + 0.442(0.513 - 0.472)^2\right]$$
$$= 0.205 \text{ in.}^4$$

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

Determine composite properties (cont'd)

The radius of gyration of the composite section with respect to the x-axis is:

$$r_x = \sqrt{\frac{I_x}{A_t}}$$

$$r_x = \sqrt{\frac{0.205}{1.674}} = 0.350 \text{ in.}$$

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

Check buckling strength of the composite section:

For compression webs, the allowable load is determined using AISC Specification Chapter E.

$$P_c = F_a A_t$$

Where,

P_c is the allowable compressive strength, P_n/Ω_c , kips

F_a is the allowable compressive stress, F_{cr}/Ω_c , ksi

A_t is the composite member cross-sectional area, in.^{2}

Safety factor, $\Omega_c = 1.67$

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

Check buckling strength of the composite section (cont'd):

Determine the yield stress to be used:

Preload, P_p = 6.9 kips

$$f_p = \frac{6.9}{(2)(0.395)} = 8.73 \text{ ksi}$$

Yield stress to be used in the minimum of:

$F_{ye} - f_p$ = **50 – 8.73 = 41.27 ksi**

F_y = **36 ksi for the rods** **Thus, use 36 ksi**

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

Check buckling strength of the composite section (cont'd):

Determine form factor, Q_s:

When $\frac{b}{t} \le 0.45\sqrt{\frac{E}{F_y}}$ $Q_s = 1.0$ **(AISC E7-10)**

$$\frac{1.5}{0.138} = 10.87 \le 0.45\sqrt{\frac{E}{F_y}} = 0.45\sqrt{\frac{29000}{36}} = 12.77$$

Thus, Q_s = 1.0

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

Check buckling strength of the composite section (cont'd):

Determine Critical Stress, F_{cr}:

When $\frac{KL}{r} \le 4.71\sqrt{\frac{E}{F_y}}$ $\quad F_{cr} = \left[0.658^{\frac{F_y}{F_e}}\right] F_y$ **(AISC E3-2)**

When $\frac{KL}{r} > 4.71\sqrt{\frac{E}{F_y}}$ $\quad F_{cr} = 0.877\, F_e$ **(AISC E3-3)**

Where $F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}$ **(AISC E3-4)**

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

Check buckling strength of the composite section (cont'd):

Compute Slenderness Ratio of Composite Section:

$$L = \sqrt{(6)^2 + (30.028)^2} = 30.62 \text{ in.}$$

$$\frac{L}{r} = \frac{30.62}{0.350} = 87.49 < 4.71\sqrt{\frac{29000}{36}} = 133.68$$

$$F_e = \frac{\pi^2 (29000)}{\left(\frac{30.62}{0.350}\right)^2} = 37.39 \text{ ksi}$$

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

Check buckling strength of the composite section (cont'd)

$$F_{cr} = \left[0.658^{\frac{36}{37.39}}\right] 36 = 24.06 \text{ ksi}$$ **(AISC E3-2)**

The available axial compressive stress is:

$$F_a = \frac{F_{cr}}{\Omega_c} = 14.41 \text{ ksi}$$

The available compressive force is:

$P_c = (14.41)(1.674) = 24.12$ kips > 18.1 kips required **Therefore, OK**

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

Design the Welds:

Total force in the welds is determined by

$$P_{rw} = \left(\frac{A_{fr}}{A_t}\right)\left(P_t - P_p\right)$$

Or, $$P_{rw} = \left(\frac{0.884}{1.674}\right)(18.1 - 6.9) = 5.91 \text{ kips}$$

Each of the 3/4" rods has an allowable force of: (14.41)(0.442) = 6.37 kips

Therefore, use this force for weld design.

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

End Web Reinforcing Weld Design:

Joint between Rod and Angle will be a partial-joint-penetration groove weld.

Effective throat thickness of 5/16 times the rod radius.

(AISC Specification Table J2.2 for Flare Bevel Groove weld)

Effective throat = 5/16 x $\frac{3/4"}{2}$ = 0.117 in.

Allowable shear per weld using E70 electrodes from AISC Table J2.5, is 2.46 kips/in.

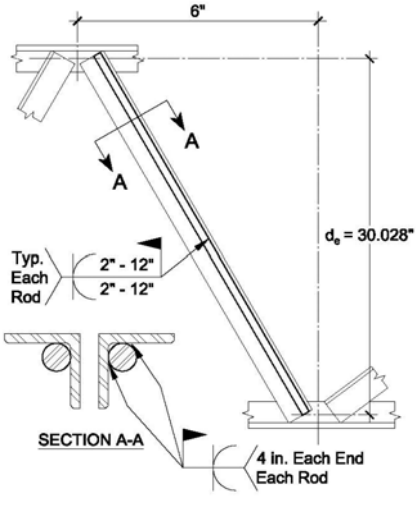
The total length of weld required to develop the force in each rod = **6.37 / 2.46 = 2.59 in.**

Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

End Web Reinforcing Weld Design (cont'd):

The 4 in. of weld that is shown in the figure at the ends of each reinforcing rod is more than adequate.

Stitch weld round rods 2" @ 12" on center.



Example 3.5 Strengthening of a LH-Series Joist with Double Angle Webs

Check Buckling of the Reinforcing between Welds:

L = weld spacing – weld length = **12 – 2 = 10 in.**

Slenderness ratio of the rod is:

$$r = \sqrt{\frac{I}{A}} = \sqrt{\frac{0.0155}{0.442}} = 0.187 \quad \frac{L}{r} = \frac{10}{0.187} = 53.4 \quad F_e = \frac{\pi^2 (29000)}{\left(\frac{10}{0.187}\right)^2} = 100.09 \text{ ksi}$$

$$F_{cr} = \left[0.658^{\frac{36}{100.09}}\right] 36 = 30.97 \text{ ksi}$$ **(AISC E3-2)**

The available axial compressive stress is:

$$F_a = \frac{F_{cr}}{\Omega_c} = \frac{30.97}{1.67} = 18.54 \text{ ksi}$$

The available compressive force is:

$P_c = (18.54)(1.674) = 31.04 \text{ kips} > 18.1 \text{ kips required}$ **Therefore, OK**

Chapter 4 Design Approaches for Modifying Joists - Shortening and Lengthening

Factors to Consider:

- **Even a small increase in length can cause a considerable increase in chord forces**
- **Web stress reversals may occur**
- **Joist camber may be adversely affected**
  - Removal of any main web member
  - Steps must be taken during modification to maintain camber
- **It may often be less expensive to obtain new joists**

Design Approaches for Modifying Joists - Shortening and Lengthening

Factors to Consider (cont'd):

- **Shortening generally does not require chord reinforcement**
  - Typically requires new bearing seats and end webs
  - An unacceptable practice is to cut the end of the top chord and bend the existing end web back up to the top chord

Design Approaches for Modifying Joists - Shortening and Lengthening

Factors to Consider (cont'd):

- **Lengthening requires the addition of reinforcing of the top chord and the web members**
  - A splice at the joist center reduces the web splice requirement
  - A splice at the joist end panel reduces the chord splice requirement but may require web reinforcement
  - A splice at both end panels generally requires no web reinforcement
- **If possible, relocate or change the support for the joists so that joist modification is not necessary**

Design Approaches for Modifying Joists - Shortening and Lengthening

Steps to Shorten Open Web Steel Joists

1. **Determine the original web layout**
   a. Top chord end panel length
   b. Interior panel length
   c. Number of panels
2. **Determine where shortened length occurs relative to top chord panels**
   a. New end web originates from a bottom chord panel point
   b. Placement angle should be 45 to 70 degrees
3. **Determine the loading at the shortened length**

Design Approaches for Modifying Joists - Shortening and Lengthening

Steps to Shorten Open Web Steel Joists (cont'd)

4. **Perform a design on the new length**
   a. Compare material required for new length to material for the as-built length
   b. Reinforce undersized existing webs as needed
5. **Place new bearing seat at the desired location**
   a. Typically a pair of angles welded between top chord angles
6. **Determine the new end web force**
   a. Typically an end web consists of two new angles
   b. Round bars may also be used on smaller **K**-Series joists with 2 ½" bearing seats

Design Approaches for Modifying Joists - Shortening and Lengthening

Steps to Lengthen Open Web Steel Joists

1. **Determine the original web layout**
   a. Top chord end panel length
   b. Interior panel length
   c. Number of panels
2. **Determine where lengthening length occurs relative to top chord panels**
   a. Limited to how much length can be added by
      1) **Slenderness ratio of new web**
      2) **Long end panel may govern top chord size**
3. **Determine the loading at the increased length**

Design Approaches for Modifying Joists - Shortening and Lengthening

Steps to Lengthen Open Web Steel Joists (cont'd)

4. **Perform a design on the new length**
   a. Compare material required for new length to material for the as-built length
   b. Reinforce chords and webs as required
5. **Place and weld new top chord angles**
   a. Use pre-qualified butt weld per AWS or
   b. Splice with new material and a weld sized to develop adequate strength

Design Approaches for Modifying Joists - Shortening and Lengthening

Steps to Lengthen Open Web Steel Joists (cont'd)

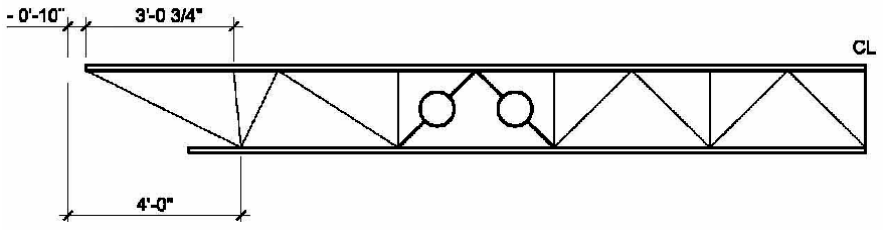
6. **Place new bearing seat at the desired location**
   a. Typically a pair of angles welded between top chord angles
7. **Determine the new end web force**
   a. Typically an end web consists of two new angles
   b. Round bars may also be used on smaller **K**-Series joists with 2 ½" bearing seats

Example 4.1 Shortening of a K - Series Joist

Given Conditions:

- A 39'-10 ½" long 24K8 joist is to be shortened by 10"
- Approximate angle of new end web:

$$\theta = \arctan (48\text{-}10)/24 = 57.7 \text{ degrees}$$



Joist to be Shortened

Example 4.1 Shortening of a K - Series Joist

Analysis and modification:

- **From the Standard ASD Load Table for Open Web Steel Joists, K-Series**
  - New total safe uniformly distributed load capacity = 293 plf
- **Analysis shows the two circled webs are overstressed**
  - Reinforce as needed
  - Webs are crimped angle web members
    - Reinforce with a pair of angles on the outside of the chords

Example 4.1 Shortening of a K - Series Joist

Analysis and modification (cont'd):

- **A new bearing seat is required**
- **Top chord angles are separated by a 1" gap**
  - A pair of 2 x 2 x 3/8" angles 4" long are welded back-to-back to form a 2 ½" deep seat

Example 4.1 Shortening of a K - Series Joist

Analysis and modification (cont'd):

- **New end web force is 10050 lbs**
  - New end web length is 37.7 in.
    - Based on clear length between 2" top chord and 1 ¾" bottom chord
  - A pair of 3/4" round bars will satisfy the strength and slenderness criteria
    - L/240 per SJI Specifications for K-Series joists
- **Using E70XX electrodes**
  - Flare-bevel groove weld strength with 3/4" rounds = 2.46 kips/in.
  - 10050/2.46 = 4.1" or 2 ¼" weld at each end of each bar

Example 4.1 Shortening of a K - Series Joist

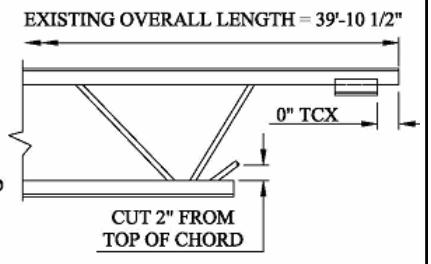
Joist Marks: J22
Total Pcs: 1

Exist O.A.L.: 39'-10 1/2"
Req'd O.A.L.: 39'-00 1/2"

Work Description: Shorten joists 0'-10" by removing top chord.

If work is performed at tag ends leave tag in place.

1. At bottom chord, cut existing end web 2" above top of angles.

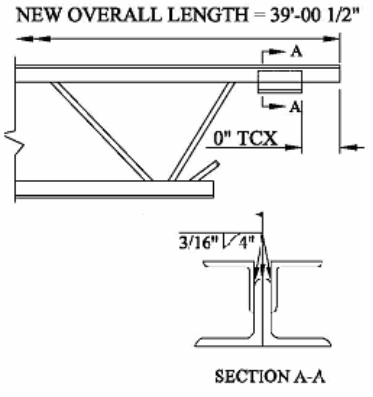


Reinforcing Detail

Example 4.1 Shortening of a K - Series Joist

2. At top chord, cut top chord back 10" removing web and chord bearings.

3. Place new bearing angles, 2 x 2 x 3/8 x 0'-4". Weld angles to top chords. See Section A-A.

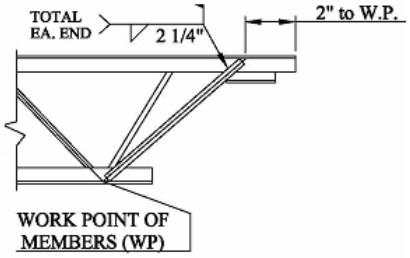


Reinforcing Detail (cont'd)

Example 4.1 Shortening of a K - Series Joist

4. Place two (one each side) new end web members, 3/4" rounds. Provide a minimum of 2 1/4" of flare bevel weld at the end of each new end web (total of 4 1/2" for two rounds). Be sure to note placement of new end webs such that the working axis of the end webs is over the first bottom chord knuckle.

Notes:
- All weld to be made with E70XX electrodes.
- All fillet weld leg lengths equal to new angle thicknesses.
- All new material to have a minimum yield strength of $F_y = 36$ ksi.
- All welds to be performed by a welder certified to A.W.S. for welds and positions required.
- Sketches not to scale.



Reinforcing Detail (cont'd)

Chapter 5 Other Considerations

Other Important Considerations

- **Deflections**
- **Camber**
- **Effects of added loads on bridging**
- **Creating two joists from one**

Other Considerations

Deflections

- **Deflection control is often required in addition to strengthening joists for load**
- **Project deflection requirements must be considered**
  - A live load deflection less than L/240 may not be met if a joist is only strengthened for added loads from a snow drift.

Other Considerations

Camber

- **When shortening or lengthening a joist, camber needs to be maintained whenever removing any web members**

Effects of Added Loads on Bridging

- **Bridging may need to be added or altered**
  - Providing lateral support to compression chord members is critical
  - Bottom chord may also be subjected to compression due to uplift
- **Designer is to refer to the SJI Specifications for bridging requirements**

Other Considerations

Creating Two Joists from One

- **Similar to shortening a joist**
- **Due to increased shear and stress reversals**
  - Many of the webs likely will require reinforcement

Other Examples included in the Digest

- **Example 5.1** Changing the Natural Frequency of a Joist System
- **Example 5.2** Reducing the Deflection of a Joist Girder

Chapter 6 Summary

Approaches have been Presented for the Modification and Strengthening of Joists

- Several types of reinforcing members presented along with attachment details
- Procedures and details do not constitute an exhaustive list of how to reinforce

They provide the designer with ideas and concepts to solve individual modification and strengthening requirements

Any Questions?

SJI Website: http://www.steeljoist.org